RedFame
Studies in Engineering and Technology
Vol. 4, No. 1; August 2017
ISSN 2330-2038 E-ISSN 2330-2046
Published by Redfame Publishing
URL: http://set.redfame.com

# Analysis of Reservoir Architecture of Shallow-water Delta Front Based on Process—A Case of S2L4$^{10}$ in Southern 79 Block in Wennan Oilfield

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Received: July 10, 2017 Accepted: July 27, 2017 Online Published: July 31, 2017

doi:10.11114/set.v4i1.2530 URL: https://doi.org/10.11114/set.v4i1.2530

**Abstract**

The sand body distribution is relatively limited in this block, the lens-shaped sandbodies are more developed, the change of intergranular sandbody is fast and the internal architecture of the sand body is complex, which results in the difficulties of the arrangement of horizontal wells in the study area and the tapping of remaining oil in high water reservoirs. In this paper, taking an example of S2L4$^{10}$ sandbodies in Wen 79 Southern Block, rich drilling data, core data, logging data and geological research results accumulated over many years in Wennan Oilfield were applied to discuss the anatomical method of the reservoir architecture unit in the underwater distributary channel in the shallow delta front, the hierarchy of the internal architecture of the reservoir and the anatomy of the single sand body. On the basis of this, the sequence of the underwater distributary channel in the composite channel is determined by the cross section and the source profile. Under the guidance of the sedimentology principle, the formation process of the underwater distributary channel is restored and the evolution process of underwater distributary channel is recovered.

**Keywords:** Wennan Oilfield, underwater distributary channel, reservoir architecture, remaining oil

## 1. Introduction

The underwater distributary channel is the main constituent element in the delta sedimentary system (Mackey & Bridge, 1995; Fielding, 2010; Wen, Wu, Wand, Yue, & Li, 2011; Singh, Bijeljic, & Blunt, 2016) and is also an important oil and gas reservoir (Wang, He, Zhang, Li, & Xu, 2004; Yin, Zhang, Gong, & Li, 2008). The research on the reservoir structure of the delta is mainly concentrated in the estuary dam, and a lot of researches have been done on its outcrop and underground reservoirs (Chen, Lin, Yin, Sun, & Wang, 2017; Lin, Chen, Shan, Sun, & Wang, 2017). As a result, fruitful results have been achieved. However, there is not enough fine research on the sedimentary unit of underwater distributary channel and its model is not clear. Therefore, the reservoir structure analysis method is needed to provide a systematic research for the fine description of the underwater distributary channel reservoir (Ray & Chakraborty, 2002; Stouthamer, Cohen, & Gouw, 2011; Lin, Shan, & Chen, 2017). The fine description of the single sand body in the reservoir in shape, scale, direction and its relationship will lay a solid geological foundation to tap the remaining oil and improve oil recovery rate in high water oil fields (Yin, Zhang, Zhao, Fan, & Li, 2001; Zhang, Yin, Yu, Ye, & Du, 2013; Fryirs, 2017; Lin, Chen, Shan, & Sun, 2017).

The Wen 79 Southern block is located in the Southern Wenliu structure, the central uplift belt in Dongpu depression(Yin et al., 2014). After more than 20 years of high-speed mining and multiple comprehensive adjustments, the cumulative oil progradation reached $109.2\times10^4$t (Zhang, 2009).However, the current recovery rate of the block is only 18.75%. And the composite water cut is 85.3%, which are far less than the level of the entire oil field, showing great potential for adjustment and prospects (Xiong, Yang, Chen, Tian, & Hong, 2003).

At present, the research scholars have the following views on the depositional system in the 79 southern block: the shallow delta sedimentary system (Zhang et al., 2010; Hu, Chen, Fan, & Hu, 2017; Hu, Fan, et al., 2017), channel sediments and terminal fan deposition (Xue et al., 2015).The sedimentary facies study of the sedimentary facies is not very clear for the internal architecture and distribution of single channel and the sedimentary microfacies can not characterize reservoir connectivity and heterogeneity clearly which is the main reason leading to the deployment of horizontal wells in the study area, and the difficulty of tapping the remaining oil in the high water cut reservoirs. Therefore, the reservoir distributary analysis technology is applied to analyze the $S2L4^{10}$ reservoir sand body of the main No.4 group reservoir of lower Es2 sub-member in the 79 southern block. Based on the deposition process, the spatial distribution of composite sand bodies is predicted by geological observation and geological data. Under the boundary constraints of composite sand bodies, the evolution of the single channel sand body is further analyzed. Through the multi-stage superposition of the channel and the analysis of the channel, such as the swing, migration, foreset and distributary process, the internal architecture of the underwater distributary channel is reconstructed. It is of great significance to accurately understand the heterogeneity of sand bodies, to predict the preferential seepage channel and to adopt the comprehensive adjustment measures to tap the remaining oil.

## 2. Geology Survey

The Wen 79 Southern block is located in the Southern Wenliu structure, the central uplift belt in Dongpu depression (Hou, 2000). It is a graben fault block lithologic reservoir in the north-east grab belt sandwiched between the Wendong east fault and the Xu Lou west fault. East to Xu Lou fault for the boundary, West to 43.6 fault for the boundary, the two faults intersect at their southern junctions Well 179-15 (Fig. 1).Fault sealing is good, the block formation is relatively complete and the fracture is not developed. Therefore, the characteristics and distribution of reservoir have a great influence on the potential of residual oil.

It has been studied that the depositional environment of lower Es2 sub-member in Wen 79 Southern Block is the intermittent uplift lake environment with seasonal climate (Xiong, Wang, et al., 2003). It belongs to the underwater delta front surface which consists of underwater distributary channel, underwater distributary channel flank, and front edge sand as sedimentary body (Huang, Zhang, Tang & Dou, 2004) (Fig.2). The main oil-bearing layer is the lower Es2 sub-member of Paleogene Shahejie Formation. Among them, the 2-5 sand group is the main oil-bearing layers (Xiong, Yang, et al., 2003). The main source is the West Huzhuangji Source (Zhang et al., 2010). The lithology of the reservoir is mainly sandstone and siltstone, and the porosity and permeability are medium.

There are 8 sand groups and 58 small layers in the lower Es2 sub-member. The main layer of the S2L4 sand group is relatively developed and the connectivity is relatively good. After more than 20 years of high-speed mining and multiple comprehensive adjustments of governance, it shows that despite the high water cut, but there are up to tens of tons of efficient adjustment wells. It also shows that there is a large number of sand bodies under the current well pattern, the flow difference is obvious, the remaining oil distribution is scattered (He & Wang, 2008; Feng, 2013), showing great adjustment potential and prospects. The distribution of sand bodies in this block is relatively limited, and the lenticular sand bodies are more developed. The sandbody changes rapidly and the internal structure of the sandbody is complex (Gao, Zheng, Chen, Zhu, & Liu 2011). Therefore, it is urgent to study the internal architecture of the reservoir of the lower Es2 sub-member in Wen 79 Southern Block by the reservoir distributary analysis technique to predict the remaining oil distribution. Reservoir heterogeneity has become the dominant factor affecting the distribution of residual oil in the area (Mao, Dai, Wang, Li, & Hu, 2016). Therefore, the author chooses the main strata No.4 sand in the lower Es2 sub-member to analyze the internal structure of the reservoir.

## 3. Hierarchical Division

Sedimentary studies have shown that sedimentary processes are hierarchical (Zhang, 1992). The genesis of the shallow sand delta is related to the change of lake plane and the periodicity of delta deposition, resulting in the relative propulsion and retraction of the phases on the plane, and the vertical stack of layers (Zhu et al., 2012). This phenomenon shows that shallow water delta sand bodies have obvious levels.

According to the reservoir architecture analysis method, combined with the current stratigraphic comparison terminology (stratum, sub-section, sand formation, small layer, etc.) adopted by Zhongyuan Oilfield and core observation results, a hierarchical architecture partitioning scheme is proposed from the viewpoint of sedimentary origin on the basis of the proposed classification of Miall (Miall, 1985, 2013, 2016) and the previous research results. The reservoir of shallow-water delta front in Wen 79 Southen Block in Zhongyuan Oilfield is divided into ten grades. From one to three, the existing classification schemes have been adopted following the oilfield. Four to seven interfaces and their defined architectural elements are the focus of the study. Eight to ten interface and its defined structural elements are difficult to track and contrast in the underground because of its small size. Therefore, it is not the focus of research.

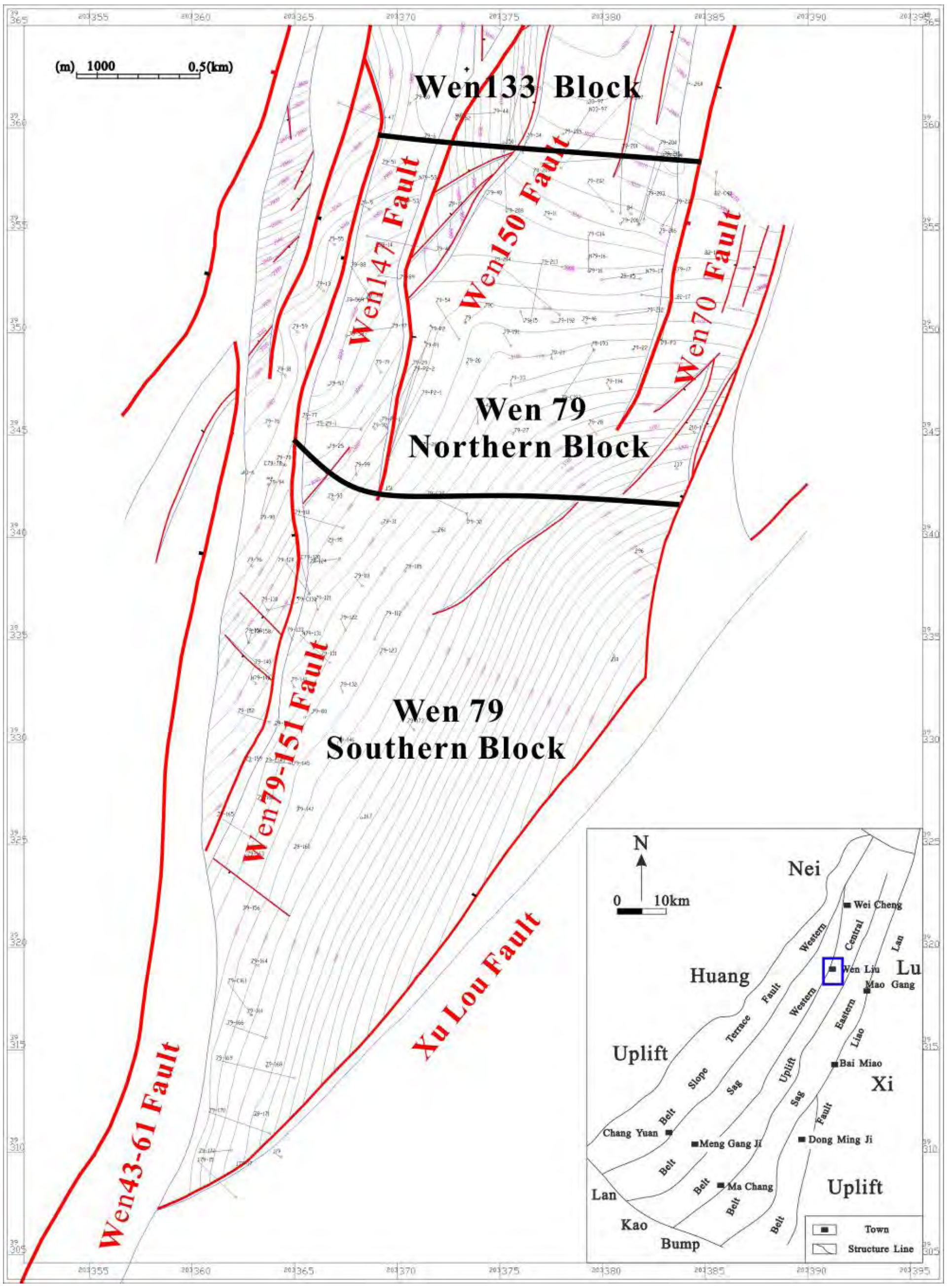


Figure 1. Regional tectonic position and well location map in Wen 79 Southern Block

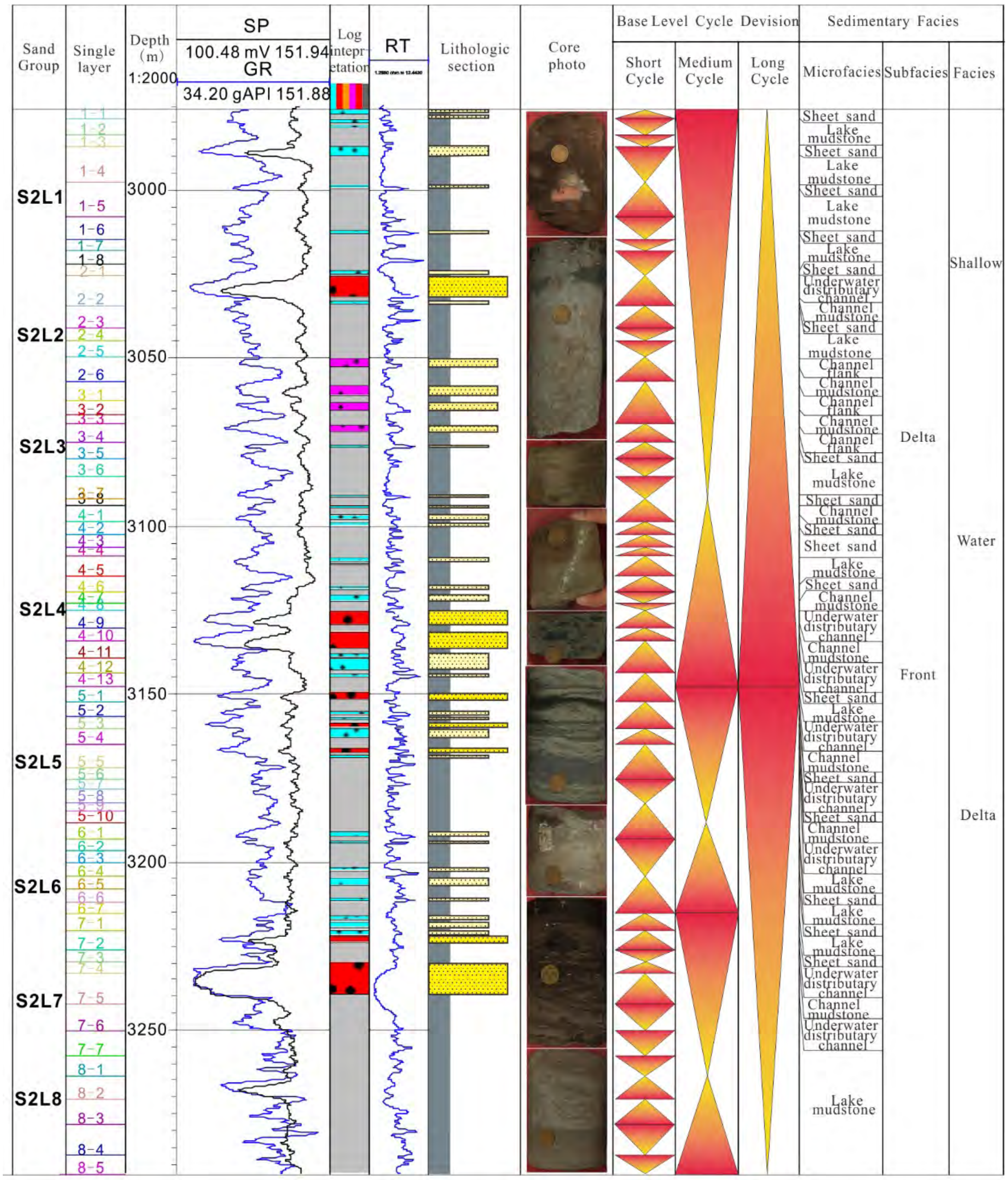


Figure 2. Stratigraphic histogram in Wen 79 Southern Block

The first level is formed in the long-term base-level rotation period, which belongs to the basin cycle under the control of the structure. It is composed of strata with a large variation of the depth of water of the deposition process. In this area, the first-level entity is a terrain or sub-section and its interface is the top and bottom interface of the terrain. From the bottom of the subparagraph to the top of the subparagraph, the lake plane in the basin is from shallow to deep and shallow, then forming a set of formation from anti-cycle to positive-cycle.

The second level is a change in the size of a delta system, representing a basin within the scope of the lake rise and fall, generally caused by structural or long-range climate fluctuations. The Es2 section of the study area is divided into Es2 and Es2, and each subparagraph is a two-level entity.

The third level is a basin-scale delta cycle that represents a basin-wide lake rise and fall, which is also caused by structural or long-range climate fluctuations. In the study area, the top-bottom interface of the sand member S2L4 is the flooded mudstone distributed throughout the region, representing a process that the lake plane is falling from rising to rise, the delta sand body is from progradation to retrogradation and sand scale is from small to large and then smaller.

The fourth level is formed in the short-term cycle, which is a small-scale progressive-retrogressive pattern formed by a more obvious water body change process. It is a single spin of a single delta thallus, that is, it is formed due to the vertical stretching or lateral swing of the delta. The fourth level entity is a small layer, which is the deposition time unit applied in the current Wennan oil field. Its interface is a top-bottom interface of a small layer, generally a stable barrier.

The fifth level is a composite sand body. The fifth level element entity in this area is a underwater distributary channel, namely the single genesis underwater distributary channel complex formed by the control of the single trunk underwater distributary channel (the initial distributary channel into the lake) of the delta, which is a set of relatively continuous formation on the plane formed in a delta flood condition or a relatively stable hydrodynamic phase. On the plane, a composite sand body consists of several single underwater distributary channel sand, channel wing sand, sheet sand and lake mud and other components. Vertically, there is generally only one cause sand body. The interface is an interlayer or an erosion surface which is among the underwater distributary channel composite sand bodies under the control of the same distributary system. It indicates the beginning or end of a set of flood events.

The sixth level is equivalent to the sedimentary microfacies, which is the geological record formed by a geomorphic unit at a geographical location within a short-term cycle, such as channel sand, channel wing sand, sheet sand and so on. The sixth level interface is a muddy barrier or muddy drape during the period of underwater distributary channel sedimentation internal. The sixth level architectural elements include underwater distributary channel sand, channel wing sand, sheet sand which are equivalent to the commonly applied microfacies.

The seventh level is the progradation sand body formed within the single underwater distributary channel during the secondary hydrodynamic condition. The interface is formed by the mudstone when the progradation sand bodies swing laterally or progradationally or retrogradationally. It also represents the beginning or end of the secondary sedimentary event in the progradation sand bodies.

The eighth level is the genetic increment, that is, the internal hyperplasia in the progradation sand bodies. It is a geological body with limited distribution formed by the sediment discontinuity or lateral migration of geomorphic elements which is caused by the water turbulence during the smaller geological process than short-term cycle. The interface is the interlayer of the sand body or its scouring surface and the entity is a part of the microfacies.

The ninth level is the cross layers. It is a more limited sedimentary body because of the changes of the sedimentary bottom which is formed by the varieties of water flow and sediment supply. Its entity is the sand body which makes up the cross layers and its interface is scouring surface or discontinuity surface on the top or bottom of the cross layers. It is equivalent to Miall's second level interface.

The tenth level is the cross layer, which is the sand layer composed of single bedding when the flow energy changes but the flow pattern don't. And the distribution is the most limited. The interface is the scouring surface of the top and bottom, and the entity is the sandbody of the composition layers. It is equivalent to Miall's first level interface.

Due to the small range of distribution, the eighth to the tenth level surface can not be tracked in the ground and can only be identified and contrasted in the outcrop and the core. The confirming of the sixth and seventh level surface needs to rebuild the underground reservoir architecture ,namely needs to dissect the reservoir.The confirming of the fifth to the first level surface can be determined by contrast.

Table 1. Hierarchical Architecture Table

| Hierarchy | Interface | Reservoir Entity | Cause | T. M. CrossCycle | Timescale /a |
|---|---|---|---|---|---|
| First level | Top and bottom interface | Stratigraphic segment | Basin cycle controlled by structure is composed of a set of strata with large water depth variation and genetic relationship with each other | Giant cycle | $10^7$~$10^8$ |
| Second level | Top and bottom interface of stratigraphic sub-segment | Subsegment | The rise and fall of a lake in the range of a basin caused by tectonic or long-term climatic fluctuations, representing a change in the size of a delta system | Super long cycle | $10^7$~$10^8$ |
| Third level | Deep Lake mudstone at the top and bottom of sand formation | Sand Group | A sequence consisting of a distinct pattern of progradation and accumulation of superimposed sedimentary facies that is composed of a distinct water body change and a series of smaller water bodies | Long Cycle | $10^6$ ~$10^7$ |
| Forth level | Mudstone or sedimentary section at the bottom of the top | Single Group | The formation of a small scale in the next phase of short-term cycle obvious change of water body formed by integral style consisting of retrogradation parasequence is a single delta of the thallus of a back spin, which is formed by the longitudinal telescopic delta or transverse swing | Medium Cycle | $10^5$ ~$10^6$ |
| Five level | Mudstone or scouring surface at the top and bottom of compound channel | Single lobe | Delta body of a single source controlled by a single distributary system | Short Cycle | $10^4$~$10^5$ |
| Six Level | Interface between the top and bottom of a single channel | Genetic sandbody | Geological records, such as channel sand, channel flank sand, sheet sand, etc., which are formed at a certain location in a short cycle | Ultrashort cycle | $10^3$~$10^4$ |
| Seven level | A deposit or barrier between the genetic bodies | Progradation | Sand body formed by sub primary water flow in a single underwater distributary channel | 7stage cycle | $10^2$ ~$10^3$ |
| Eight level | Erosion surface or the sedimentary section | Internal accretion in Progradation | The geologic body formed by a smaller scale of geological action than the super short-term cycle, and the geological body with a limited distribution caused by the discontinuous or lateral migration | 8stage cycle | $10^0$ ~$10^1$ |
| Nine level | Interface of cross stratum groups | cross stratum groups | Progradation of a change in the flow pattern | 9stage cycle | $10^-$ ~$10^{-1}$ |
| Ten level | Interface of cross stratum | cross stratum | Progradation of constant flow and constant flow | — | $10^-$ ~$10^{-5}$ |

## 4. Single Underwater Distributary Channel Identification

### *4.1 Single Body Recognition*

Anatomy of the sandbody is at a small level. At present, the sedimentation time unit applied in the oil field is the result of fine stratigraphy in the high-resolution sequence stratigraphic framework. The small-level sand body is isochronous, therefore, it is reasonable to identify the single body on the basis of the division of the small layer with the log data. It is proved that the stratigraphic layer is controlled by the sequence of sedimentary cycles and the stratigraphic formation of the shallow delta system which is especially suitable for the shallow stratigraphic system.

The single body is formed by a lot of underwater distributary channel. Due to the differences in the number of sediments carried by different trunk subsoil distributions and the differences of hydrodynamic conditions, the sedimentary characteristics of the main channel and the distribution direction of the single channel controlled by the trunk underwater distributary channel is different. At the same time, the single genetic monomer is separated by a wide range of underwater distributary bay mudslides and overflowing sandy sand. And the widely distributed underwater distributary bay mudstone and sandy sand can also be applied as identification marks for the single genetic body. By identifying the mudstone pinch area to determine the direction of the development of different sources of the system, a separate distributary system controls the formation of a single body sand body with a separate development and different characteristics. It will help us to determine the development of large borders of the single sand body.

Based on the above analysis of the deposition process, combined with the analysis of the morphology and sedimentary microfacies distribution of the plane sandbody, it is concluded that there are five single genes in $S2L4^{10}$ of Wen 79 South Block.

1) The main flow direction of channel showed from the sedimentary microfacies distribution of the layer $S2L4^{10}$ provides us with reference for determining the source direction of the stratum. As shown in Fig.3, the distribution of the microfacies of the $S2L4^{10}$ shows that the main channel flows mainly in the three directions: northeast, northwest, and northwest. The main development of seven independent development of the composite sand body. There are seven sets of independent development of the composite sand body. Since the sedimentary microfacies are the dominant facies of sandbody distribution, the internal distribution characteristics of sand bodies can not be accurately identified and It needs to be further determined according to the deposition process of composite sand bodies.

2) As shown in Fig.3, the $S2L4^{10}$ small layer can clearly predict the six complex sand body systems. According to the logging interpretation and the widely distributed underwater distributary bay mudstone and sheet sand, the composite channel can be defined under different distributary systems. The six independent developed sand bodies are continuously distributed and between them, there are widely deposited mudstone, which can be divided into the outer boundary of the composite sand body.

3) In the profile, the composite channel boundary will be further determined. According to the sedimentary microfacies and the interpretation of the good diagram, the boundary of the composite sandbody formed under the control of the distributary system is only a rough boundary. In Fig.3, the four composite sand bodies I, II, III and V are tentatively delineated and the distribution is limited. The mudstone between each distributary system is wider and contiguous, and its boundary has a greater degree of credibility. However, the distribution of the composite sand bodies formed by other distributary systems is relatively wide and the boundary area is relatively large. Therefore it is necessary to further track the boundary of its internal composite channel through the profile. It is necessary to maximize the accuracy of its internal single composite channel boundary as far as possible to provide a basis for anatomy for the next compound channel within the single channel architecture.

The method of determining the single composite channel boundary within the outer boundary of the complex composite sand is to establish a section near the source direction and perpendicular to the source direction. The size and direction of the composite channel formed under different distributary system are different. The size, magnitude and smoothness of the GR logging curve in the study area have a good response to the size of the sand body, the hydrodynamic force during the deposition process and the supply of the source. According to this, the GR curve can be applied to delimit the vertical distribution of the complex sand bodies III and IV in the cross section.

As shown in Fig. 4, cross sections H1, H2 and H3 were established. According to the mudstone and diffuse sand in the channel, two distinct sand bodies are identified, which are controlled by different distributary systems. As a result, large-scale distribution of sand can be further accurately identified as two sets of different distributary system of composite channel sand.

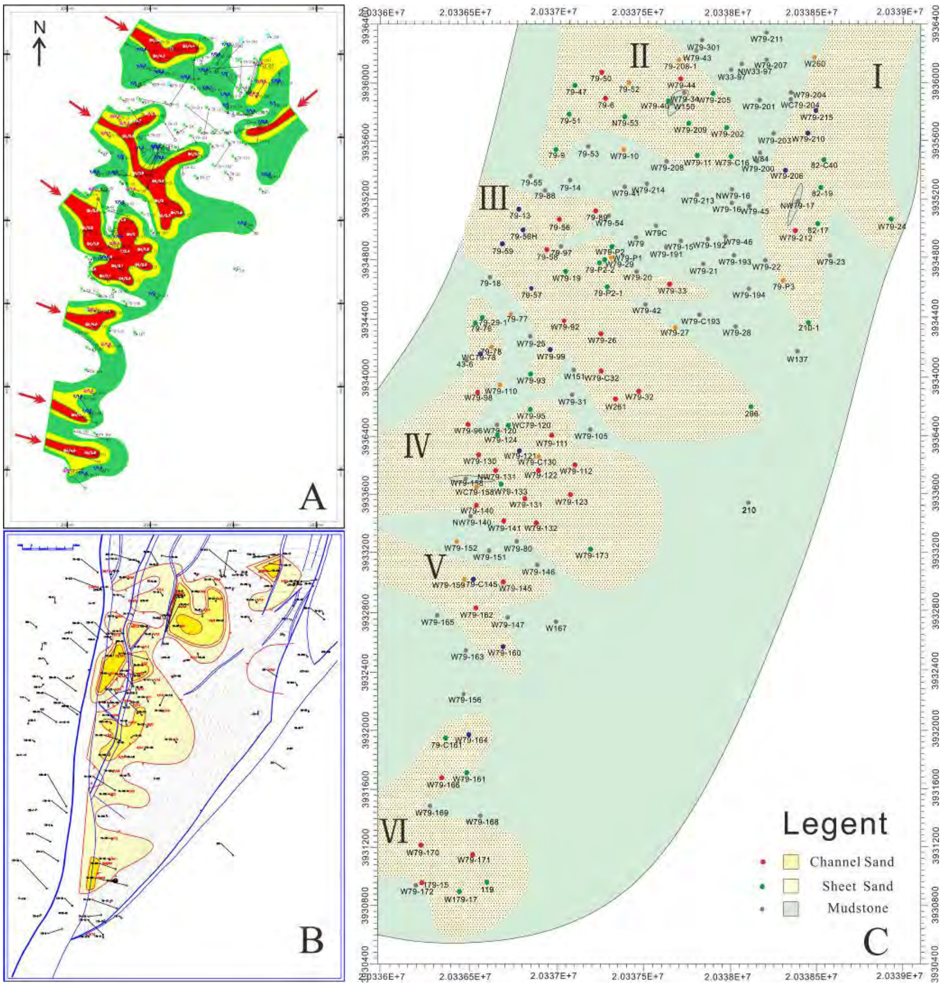


Figure 3. Schematic diagram of the initial division of the outer boundary of the composite sand in S2L4[10]

**A)** Diagram of sedimentary microfacies in S2L4[10], illustrating the distribution direction and aera of main sands. **B**) Contour map of permeability in S2L4[10], illustrating the distribution of hypertonic zones. **C**) Diagram of the outer boundary of the composite sand in S2L4[10], illustrating the distribution of the composite sand.

According to the above method, under the control of the six different distributary systems of S2L4[10] small layer, the outer boundary of the composite channel distribution is identified. See Figure 3.

*4.2 Identification of Single Underwater Distributary Channel*

According to the analytic hierarchy process, the single channel is further identified under the constraint of the large boundary of the compound channel. The sedimentation of the composite channel has a relatively stable and continuous distribution of mudstone. The good response is better and easy to identify. However, the change of the single channel in the compound channel is frequent. As a result, the sediments deposited at the bottom of the channel are not easily preserved and the top mudstone deposited in the intermittent period of the flood is easily damaged by the next single channel.

In the vertical direction, the division of a single channel can be realized by the identification of the four-stage interface, and the single-channel sand body of the underwater distributary channel is divided into different channel sand bodies. However, it is more difficult to describe the distribution of each single channel in terms of the single channel that is deposited over the same period. According to the law of sedimentation, the continuity of the channel sand body in the direction of the source is better, and the continuity in the vertical source direction is poor, and the lithology and scale are regular. Therefore, relative to the identification of composite channel, a single channel identification is not easy, which need to take other ways to track identification.

The research ideas are as follows:

For the composite channel area with small distribution area, small thickness, intertidal mudstone, and its relative developed sheet sand, the internal single channel identification division can be determined more accurately by plane and along the source profile, for example, the four composite channels Ⅰ, Ⅱ, Ⅴ, Ⅵ can be identified by logging interpretation plan and sand body thickness distribution map. First, according to the main streamlines of the channel, the main flow direction of the composite channel is predicted. Then, according to the inter-channel mudstone and thin-decked sand, the single channel boundary is traced to determine the single channel of the structural entity within the boundary.

For the large-scale complex channel, such as the complex channel Ⅲ, Ⅳ, especially the complex channel Ⅳ system, the internal single channel identification division needs to be carried out by cross-section sand body. Under the guidance of the depositional model of the study area, the reasonable combination of the sand body and the sand body shape and the channel width deposition are predicted.

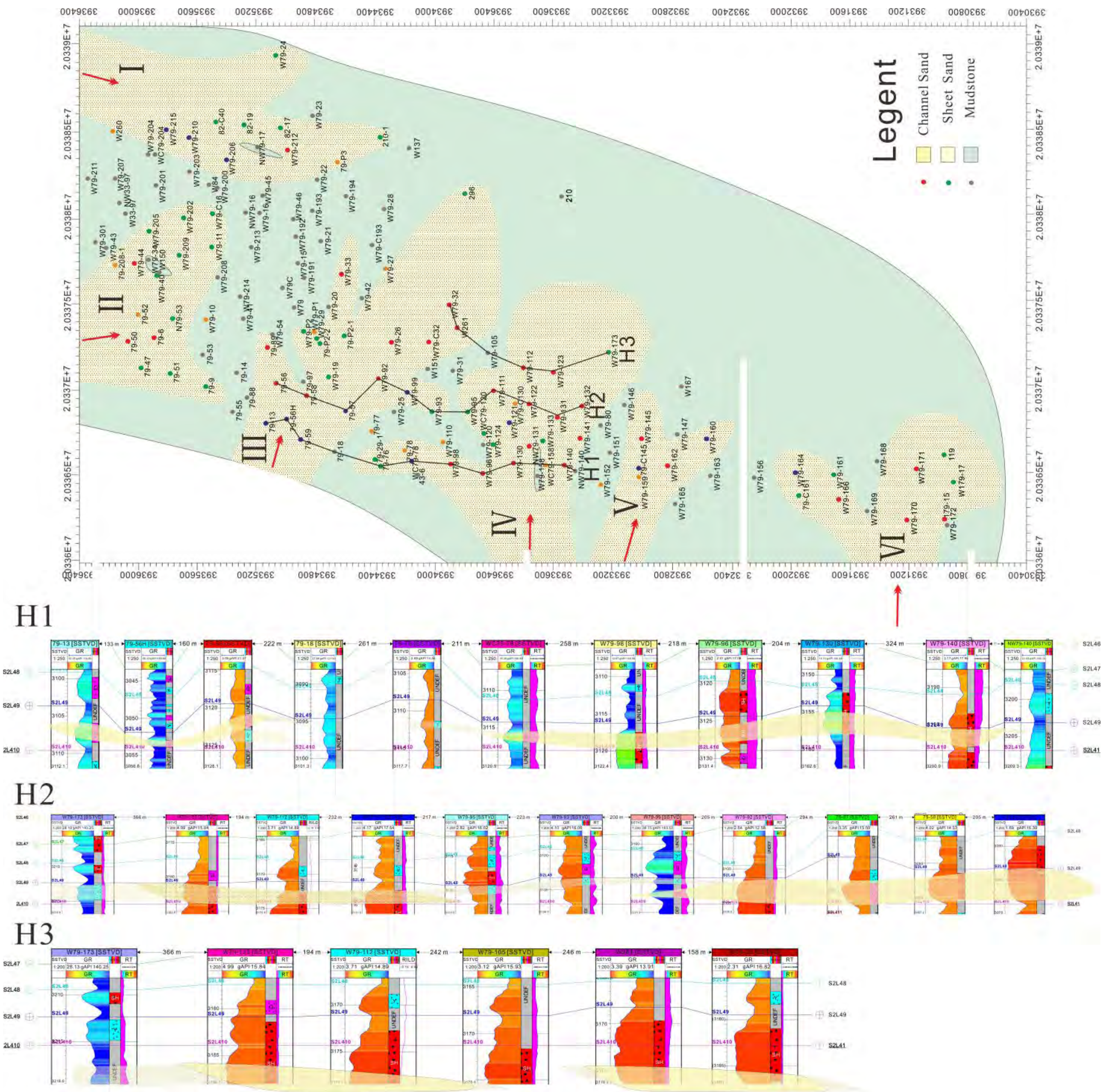


Figure 4. Schematic diagram of a single underwater distributary channel transverce sections

The division of the single channel in the study area is summarized as follows:

1) The width of a single channel is generally within 200m and the trend of channel width evolution is from source to Lake. With the frequent bifurcation of the channel, its width gradually narrowed, generally for the upper channel width of 1/2.

2) On the source profile, the single channel sand body shape is mainly striped, the plane is dendritic. The vertical source of the cross-section of the sand body shape is mainly the top flat concave-concave bowl or dish.

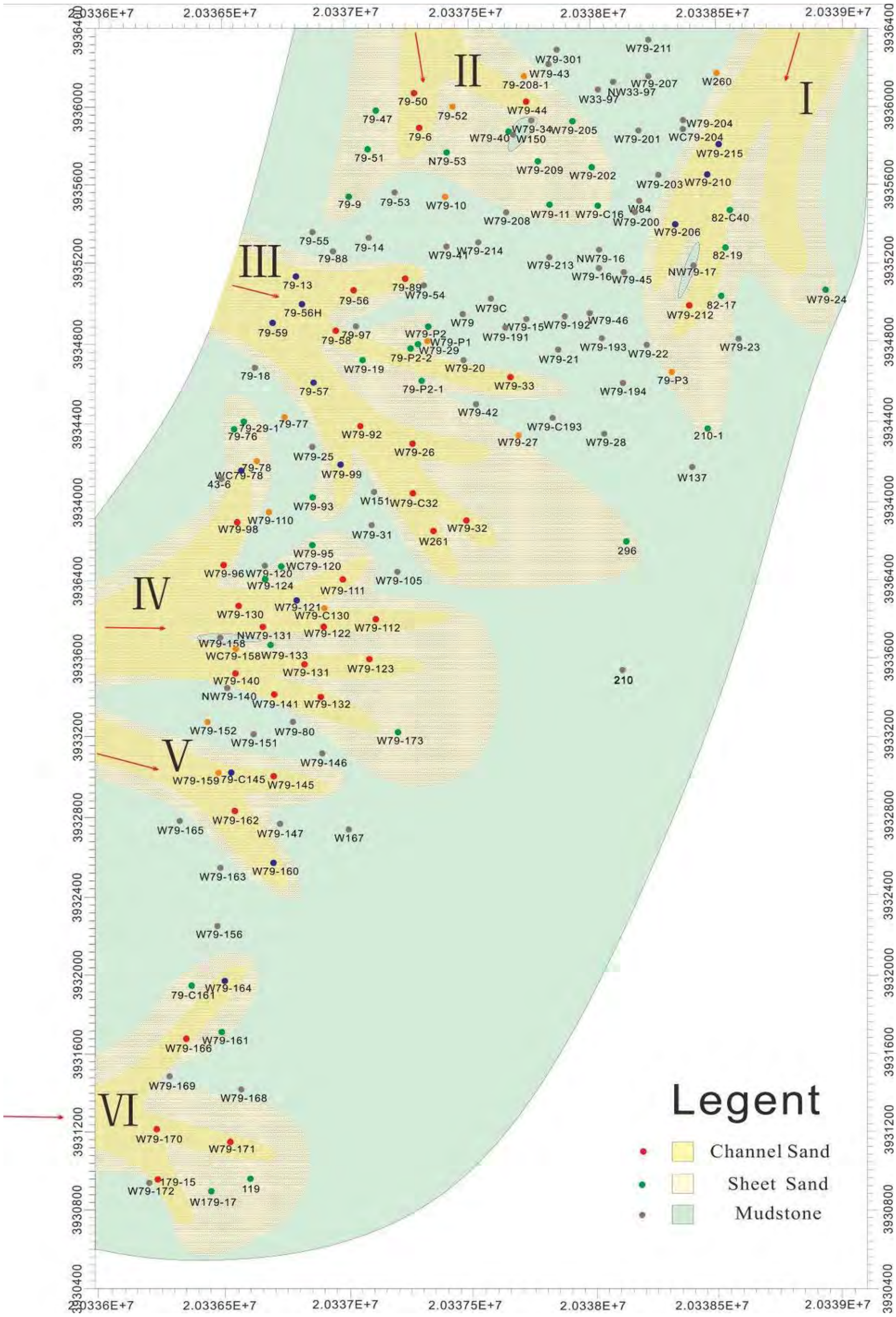


Figure 5. S2L4[10] single underwater distributary channel plane distribution map

3) Single distributary channel bending angle is not large, and the swing range is small, generally not more than 45 °.

4) There are a relatively obvious mudstone compartment and a wide distribution of sheet sand in a single distributary channel.

5) The difference between the thickness and the size of the single channel is not significant, and the single channel has obvious difference and thickness difference.

6) The single channel of the same composite channel is on the longitudinal profile of the source. From the center of the channel to the side of the channel, the GR curve has a change from box type to Christmas tree type.

According to the above analysis, the possible boundary of a single channel is shown in Fig.5

## 5. Anatomy of the Internal Architecture of Underwater Distributary Channel

### *5.1 Identification of Underwater Distributary Channel Internal Architecture*

The difference between the different precursors is characterized by mudstone or low permeability interlayer so that the remaining oil is unevenly distributed. Therefore, it is necessary to identify the progradation.

According to the sedimentation rule and sedimentary evolution trend of the sandbody, a reasonable analysis of the vertical and horizontal cross sections is carried out under the single channel boundary constraint, and the progradation formed by the secondary hydrodynamic control within the single channel are identified. It is considered that the basic architecture elements of the single underwater distributary channel in the shallow delta front of the study area are the progradation.

1) As with a single underwater distributary channel, the logarithmic response of the sand body to the source profile is as follows: from the middle of the channel to the box type - the Christmas tree type - the funnel shape.

2) The mudstone interface between the sand bodies can be identified on the logging curve.

3) By the width of a single channel sand body by the single channel level of the anatomy, statistics can be obtained in the study area of a single channel width is generally about 200m.The width of the progradation is also within the upper limit of its width and is not wider than the underwater distributary channel where it is located. And the swing amplitude of single channel sand body is not large and the shape is dendritic. Under the constraints of this deposition rule, the progradation can be identified by combining the plane distribution feature.

4) In the vertical cross section of the source, the mudstone of the distributary bay and the differences between the top elevation of the channel and the differences of the channel scale are applied to identify the progradation.

### *5.2 The Hierarchy Division of Progradation*

Although the above-mentioned study showed the distribution characteristics of the single-generation underwater distributary channel, the identification of the internal progradation must be analyzed based on its formation process to restore the internal architecture of the reservoir and thus to match with the underground real sand body 2 distribution. According to the simple data analysis based on geological features and statistics, the anatomy of the unstructured in the underwater distributary channel is mostly based on the deposition simulation experiment and the numerical simulation experiment. However, the study of underground geological bodies is less, which is caused by the complexity and uncertainty of underground channel architecture.

Therefore, this paper will use the advantages of $S2L4^{10}$small-layer underwater distributary channel development, good logging data quality, and abundant geological data. Through the establishment of multiple cross-sectional profiles, combined with one - dimensional six - level architecture of the physical plane map. The sedimentary evolution sequence of the internal architecture of the underwater distributary channel is established, and the sedimentation process of the sand body is finally restored.

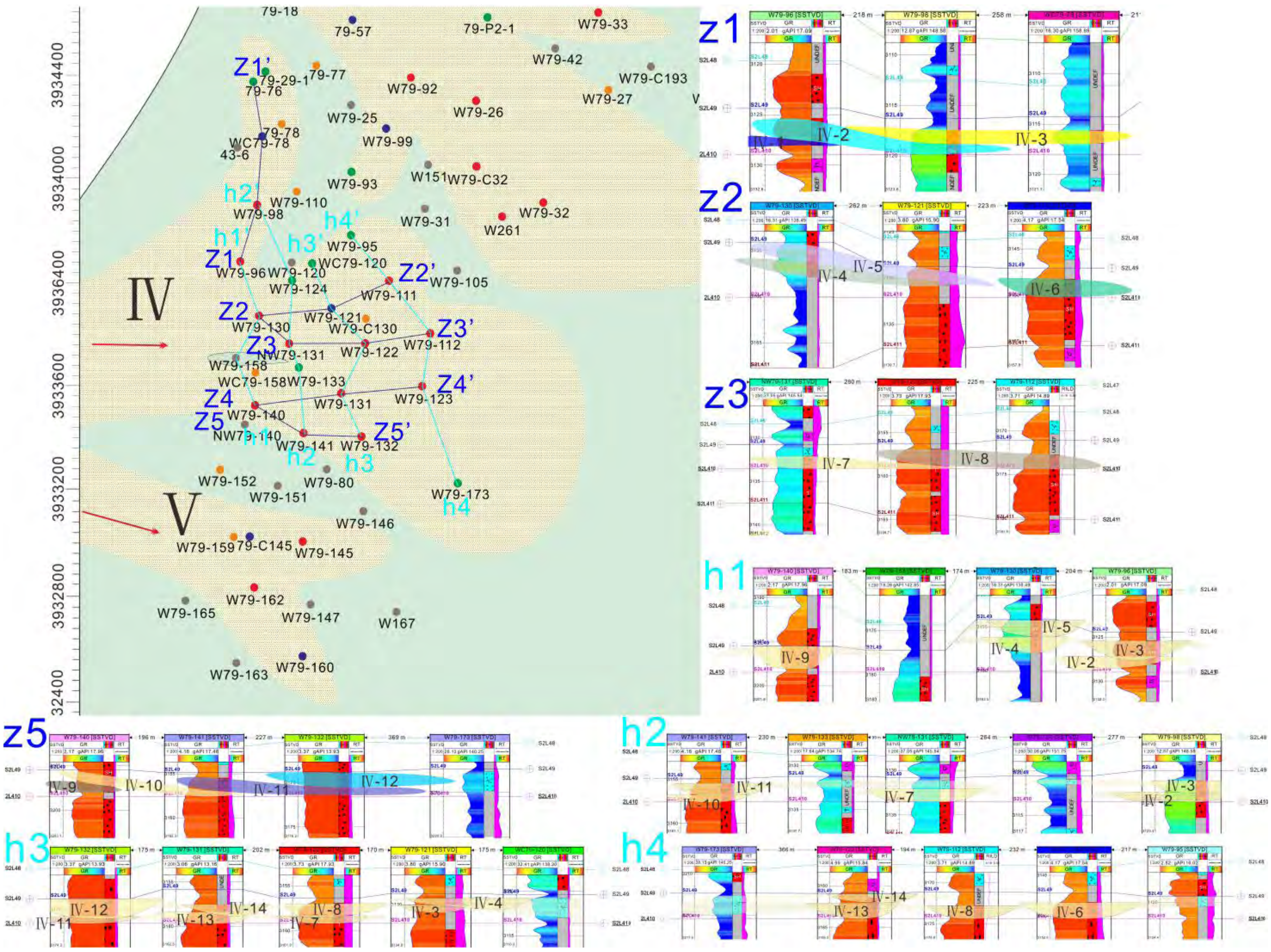


Figure 6. S2L4[10] single underwater distributary channel plane distribution map

As shown in the figure, the establishment of four cross sections and vertical profile were built in the complex channel Ⅳ with developed sand bodies.

According to the anatomical results, combined with the distribution of the progradation on the plane, the evolution of the progradation plane distribution evolution. The evolution of the plane distribution of the progradation is restored.S2L4[10] composite sand bodies Ⅳ occurred in a total of four sedimentary evolution, and each stage represents a flood event. During this period, an initial progradation was deposited after each flood event. The hydrodynamic size and direction of each flood result in the distributary channel swing, migration, unloading of the underwater distributary channel in the accommodable space. The overall trend is to advance to the lake and continue to transform the early sand bodies.

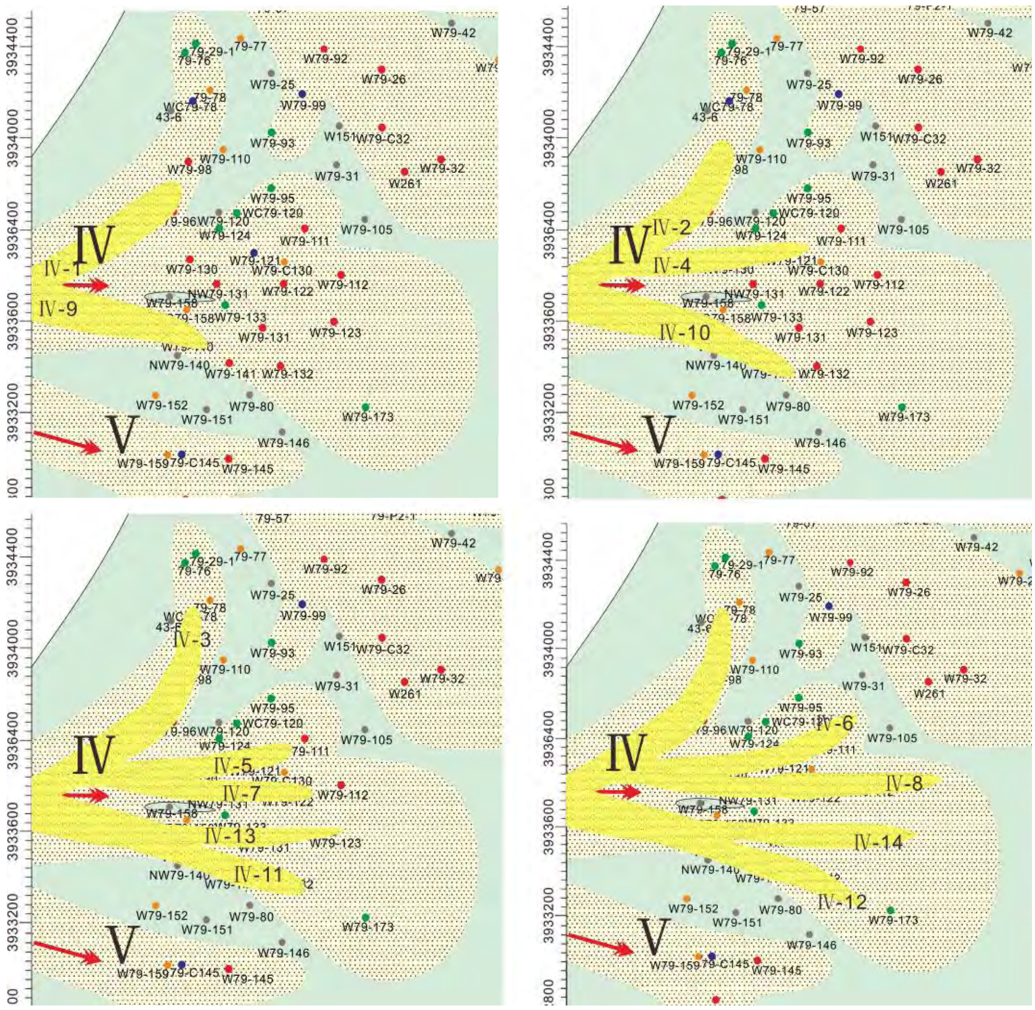


Figure 7. S2L4[10] single underwater distributary channel plane distribution map

The first phase, the main channel fork occurred the first fork, forming the south and north east of the two distributary channel. And North-east flow of the channel was significantly larger than the southeast. The channel carries sediments, depositing two preforms IV-9 and IV-1, respectively.

The second phase, southeast of the distributary channel occurred a fork. One continued to the northeast into the progradation, the other toward the east to the flow. Finally, two preforms IV-2 and IV-4 were formed. North-east of the distributary channel continues to the southeast, forming a progradation Ⅳ-10, and the channel has not yet bifurcated.

The third phase, the northeast of the distributary channel occurred a fork, forming a distributary channel eastward. And the other distributary channel migrates southward, forming the progradation Ⅳ-14 and Ⅳ-12 respectively. The distributary channel in the eastern direction is further divided into two sub-distributary channels and advanced eastward and northeastward respectively. Then two sets of progradations, IV-7 and IV-5, were deposited. The most northern underwater distributary channel is gradually abandoned. The progradation Ⅳ-3 is small, and it can be seen that the sedimentary hydrodynamics is weak.

The fourth phase, the northern part of the channel did not occur deposition, and sand body tipped off. The fourth stage of the channel mainly moves to the east and southeast. Four single underwater distributary channel formed in the previous period further forward. The channel hydrodynamic is enough large and the source of supply is also full, so the four progradations are more developed and the thickness is larger. Progradation Ⅳ-6, Ⅳ-8, IV-14, and IV-12 were deposited from east to south.

According to the above analysis, the sedimentary evolution process and the sequence of the sand body are restored, so it can be applied to analyze the structure of the underwater distributary channel in the whole study area.

In the deposition process, sand bodies are influenced by the channel and the lake. The channel construction is dominant, thus underwater distributary channel sand bodies cut with each other frequently, and the underwater distributary channel sandbody has a large thickness of overlap and wide distribution. In addition, terrigenous clastic particles brought into the lake basin by underwater distributary channels have also been transformed by lake waves, and are obviously sheeted. And the underwater distributary channel sand is formed on both sides of underwater distributary channel sand body. At the end of the underwater distributary channel, the estuarine dam deposits are formed with the weakening of the water flow intensity and the unloading of sediments. However, most of the estuarine dam sand bodies are not preserved or changed due to the late underwater distributary channel sand body's impact on the lower cut of the estuarine dam sand bodies or the transformation of the lake wave.

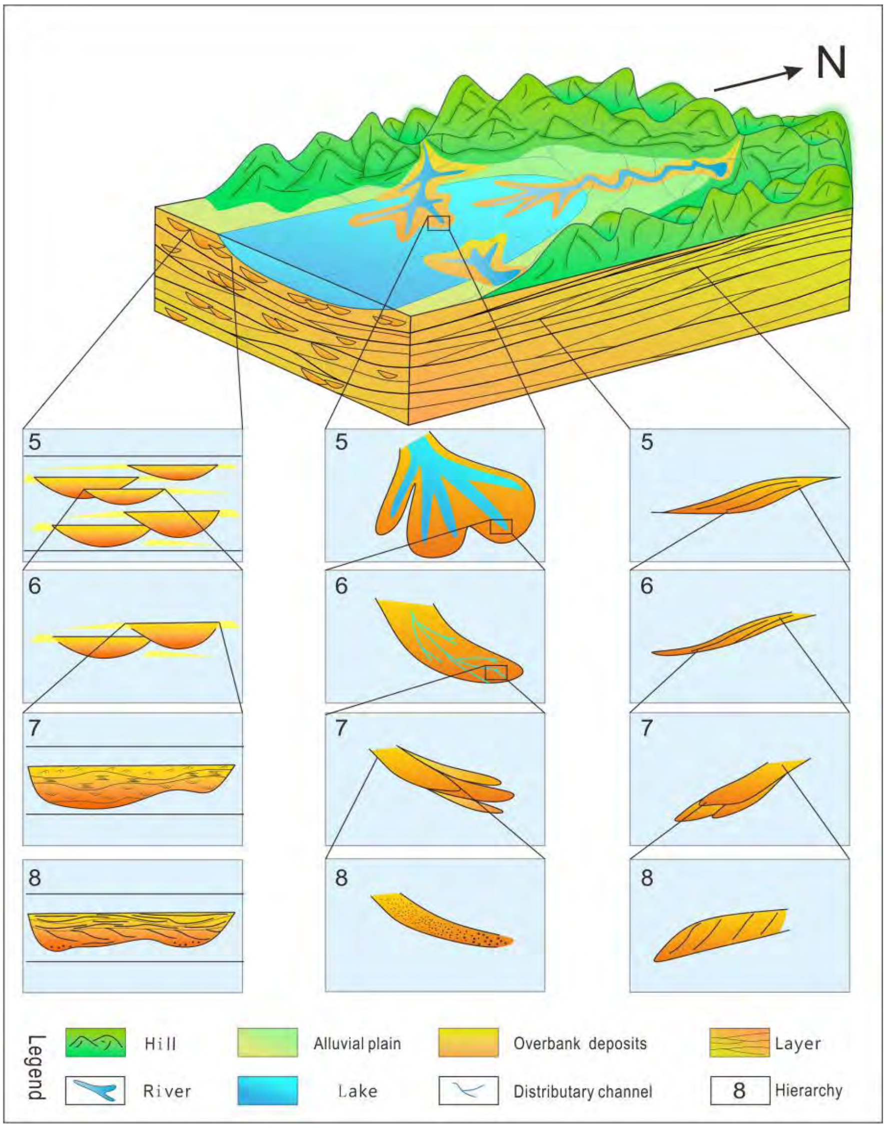


Figure 8. The division of the South level

## 6. Conclusion

(1) The reservoir hierarchical grading system of the upper Es2 sub-member in Wen 79 South Block is clarified, and the hierarchical division scheme of underwater distributary channel based on the sedimentary process is established. The study area is divided into ten levels, and four to six interfaces and its defined architectural elements are the focus of the study.

(2) In S2L4[10] of Wen 79 South Block, six underwater composite channel sand bodies and 21 single underwater distributary channels were developed. And the internal structure of the underwater distributary channel of the composite sand body Ⅳ was fine dissected and its deposition process was restored which has gone through four periods, and the size and direction of the progradations formed in different periods have a good correspondence with the logging curves.

**Acknowledgments**

The project received co-financial support from the National Major Project (2016ZX05058001-002), and Research on Fine Description of Facies Controlled Reservoirs and High-adjustment Technology (2016KF02).

**References**


Chen, L., Lin, Z., Yin, T., Sun, Q., & Wang, F. (2017). Meandering Process and Migration Architecture: Based on the Nowitna River. *Earth Science Research, 6*(2), 76-90. https://doi.org/10.5539/esr.v6n2p76

Feng, Z. (2013). *Chinese sedimentology (Second Edition)*. Beijing: Petroleum Industry Press.

Fielding, C. R. (2010). Planform and Facies Variability in Asymmetric Deltas: Facies Analysis and Depositional Architecture of the Turonian Ferron Sandstone in the Western Henry Mountains, South-Central Utah, USA. *Journal of Sedimentary Research, 80*(5-6), 1-6. https://doi.org/10.2110/jsr.2010.047

Fryirs, K. A. (2017). River sensitivity: a lost foundation concept in fluvial geomorphology. *Earth Surface Processes and Landforms, 42*(1), 55-70. https://doi.org/10.1002/esp.3940

Gao, H., Zheng, R., Chen, F., Zhu, D., & Liu , X. (2011). Features of the Paleogene Shahejie Formation in the northern Dongpu Sag. *Journal of Yangtze University (Natural Science Edition), 38*(2), 356-373. http://dx.doi.org/10.3969/j.issn.1000-3657.2011.02.011

He, Y., & Wang, W. (2008). *Sedimentary rocks and sedimentary facies*. Beijing: Petroleum Industry Press.

Hou, J. (2000). An Analysis of Sedimentary Microfacies and Production Response for the Lower Part of the Second Shahejie Sub-Member in Block Wen-79 in The South of Wenliu Oil Field. *Petroleum Exploration and Development, 27*(6), 65-67. http://dx.doi.org/10.3321/j.issn:1000-0747.2000.06.029

Hu, G., Chen, F., Fan, T., & Hu, Y. (2017). Subdividing and comparing method of the fluvial facies reservoirs based on the complex sandbody architectures. *Petroleum Geology & Oilfield Development in Daqing, 36*(2), 12-18. http://dx.doi.org/1000-3754（2017）02-0012-07

Hu, G., Fan, T., Chen, F., Jing, Y., Wand, H., & Song, L. (2017). From Reservoir Architecture to Seismic Architecture Facies: Characteristic Method of a High-Resolution Fluvial Facies Model. *Acta Geographica Sinica, 91*(2), 465-478.

Huang, Y., Zhang, C., Tang, J., & Dou, H. (2004). Relationship between sedimentary microfacies and oil-bearing probability of lower Es2 in Wen79 block of Wenliu area. *Petroleum Geology and Recovery Efficiency, 11*(5), 36-38. http://dx.doi.org/10.3969/j.issn.1009-9603.2004.05.012

Lin, Z., Chen, L., Shan, J., & Sun, Q. (2017). Channel Planform Migration Architecture of Meandering Rivers. *Asian Journal of Science and Technology, 8*(6), 4902-4911.

Lin, Z., Chen, L., Shan, J., Sun, Q., & Wang, Y. (2017). Migration structures of meandering channels. *International Journal of Information Research and Review, 6*(4), 4213-4221.

Lin, Z., Shan, J., & Chen, L. (2017). Geomorphology Processes of Channel Planform Migration on Meandering Rivers. *Acta Geographica Sinica (English Edition), 91*, 134-135. https://doi.org/10.1111/1755-6724.13223

Mackey, S. D., & Bridge, J. S. (1995). Three-dimensional model of alluvial stratigraphy: theory and application. *Journal of Sedimentary Research, 65*(1). https://doi.org/10.1306/D42681D5-2B26-11D7-8648000102C1865D

Mao, L., Dai, S., Wang, K., Li, D., & Hu, L. (2016). Fine Description and Potential Tapping Technique of Narrow Channel Sand Body -- Taking the Lower Two Member of Shahejie Formation as an Example. *Journal of Yangtze University (Natural Science Edition), 13*(29), 9-12. http://dx.doi.org/10.3969/j.issn.1673-1409(s).2016.29.004

Miall, A. D. (1985). Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. *Earth-Science Reviews, 22*(4), 261-308. https://doi.org/10.1016/0012-8252(85)90001-7

Miall, A. D. (2013). *The geology of fluvial deposits: sedimentary facies, basin analysis, and petroleum geology*: Springer.

Miall, A. D. (2016). Facies Models *Stratigraphy: A Modern Synthesis* (pp. 161-214): Springer. https://doi.org/10.1007/978-3-319-24304-7_4

Ray, S., & Chakraborty, T. (2002). Lower Gondwana fluvial succession of the Pench–Kanhan valley, India: stratigraphic architecture and depositional controls. *Sedimentary Geology, 151*(3), 243-271. https://doi.org/10.1016/S0037-0738(01)00260-3

Singh, K., Bijeljic, B., & Blunt, M. J. (2016). Imaging of oil layers, curvature, and contact angle in a mixed‐wet and a water‐wet carbonate rock. *Water Resources Research*. https://doi.org/10.1002/2015WR018072

Stouthamer, E., Cohen, K., & Gouw, M. J. (2011). Avulsion and its implications for fluvial-deltaic architecture: insights from the Holocene Rhine-Meuse delta. *SEPM Special Publication, 97*, 215-232. https://doi.org/10.2110/sepmsp.097.215

Wang, Z., He, Z., Zhang, C., Li, S., & Xu, L. (2004). Analysis on Reservoir Hierarchy of Deltaic Front Outcrops--Taking Tanjiahe Outcrop in Eastern Ordos Basin for Example. *Journal of Jianghan Petroleum Institute, 26*(4), 32-35. http://dx.doi.org/10.3969/j.issn.1000-9752.2004.04.010

Wen, L., Wu, S., Wand, Y., Yue, D., & Li, Y. (2011). An accurate method for anatomizing architecture of subsurface reservoir in mouth bar of fluvial dominated delta. *Journal of Central South University, 42*(4), 1072-1078.

Xiong, Y., Wang, D., Li, C., Tian, S., Gao, Y., & Tan, X. (2003). Study on Feature of Sedimentary Microfacies of Lower Es2 (Eogene) in Wennan Oilfield. *Geological Science and Technology Information, 22*(1), 61-66. http://dx.doi.org/10.3969/j.issn.1000-7849.2003.01.012

Xiong, Y., Yang, J., Chen, Y., Tian, C., & Hong, Y. (2003). The Fine Studies of Depositional Micro-Facies on The Middle-Post Development Stages in Wennan Oilfield. *Petroleum Exploration and Development, 30*(2), 64-67. http://dx.doi.org/10.3321/j.issn:1000-0747.2003.02.018

Xue, H., Zhang, J., Li, J., Sun, Z., Yu, T., & Wang, G. (2015). High-resolution sequence stratigraphy model of Es22 in W79 block,Dongpu depression. *China Science Paper,* (15), 1752-1756. http://dx.doi.org/10.3969/j.issn.2095-2783.2015.15.004

Yin, T., Zhang, C., Gong, F., & Li, S. (2008). Application of Sand Body Framework Superposed Graph to Reservoir Prediction. *Journal of Jianghan Petroleum Institute, 29*(6), 832-836. http://dx.doi.org/10.3321/j.issn:0253-2697.2008.06.008

Yin, T., Zhang, C., Zhao, H., Fan, Z., & Li, Z. (2001). Remaining oil distribution prediction based on high-resolution sequence stratigraphy. *Petroleum Exploration and Development, 28*(4), 79-82.

Yin, T., Zhang, C., Zhu, Y., Yang, W., Ye, J., Cai , W., & Dai , Y. (2014). Overlapping Delta: A New Special Type of Delta Formed by Overlapped Lobes. *Acta Geologica Sinica (English Edition), 88*(2), 263-272.

Zhang, C. (1992). Hierarchy Analysis in Reservoir Researches. *Oil and gas geology, 13*(3), 344-350.

Zhang, C., Yin, T., Yu, C., Ye, J., & Du, Q. (2013). Reservoir architectural analysis of meandering channel sandstone in the delta plain based on the depositional process. *Acta Sedimentologica Sinica, 31*(4), 653-662.

Zhang, F. (2009). *Fine Reservoir Description of South Wen79 Block.*

Zhang, W., Chag, Z., Yuan, W., Li, Z., Wei, X., Li, X., & Xie, Y. (2010). Sedimentary facies and their evolution in the lower submember of the 2nd member of the Shahejie Formation in the Wennan Oil Field. *Sedimentary Geology and Tethyan Geology, 30*(4). http://dx.doi.org/10.3969/j.issn.1009-3850.2010.04.013

Zhu, X., Liu, Y., Fang , Q., Li, Y., Liu , Y., Wang, R., ... Liu, X. (2012). Formation and Sedimentary Model of Shallow Delta in Large-Scale Lake: Example from Cretaceous Quantou Formation in Sanzhao Sag, Songliao Basin. *Earth Science Frontiers 19*(1), 89-99.